RUSTING OF PIPE IN SERVICE[1]

By Harry Y. Carson

The history of pipe is the history of civilization. Upon no other single product have the great cities of the world depended in such large measure for their health and comfort. The modern city is dependent upon pipe as we are dependent upon arteries, veins and capillaries in human bodies. Let us compare our modern buildings to the individual cells in our body. These cells receive their life-renewing supply of wholesome water through multitudinous pipes, permeating every wall and corridor. After the water has supplied life, bathed and cleansed to its utmost, it carries off the waste products through other capillaries, collecting into larger and still larger main trunk arteries. We are taught that man has a natural life of three score and ten years, but would he not have a life of only five years if his capillaries were constructed to last but that long? If his capillaries were built on the century basis and his arteries on the ten year basis what would be the ultimate result?

Cast iron and wrought pipe compared. Pipe made in a rolling mill does not resist corrosion in service so well as pipe made in a foundry. Both kinds of pipe may have been made from the same quality of iron ore: both are smelted and both may have been treated in the same manner up to a certain point in their refinement known as the "pig iron" stage. The iron which passes though a tube mill must first of all be rendered comparatively free from carbon, silicon, sulphur, phosphorus and manganese before it can be manipulated into thinly rolled sheets for the purpose of making wrought pipe. Paradoxical as it may seem to the layman's mind, the question of chemical refinement plays small part in comparison to other factors. These factors which make for rust resistance of metal pipe have heretofore been given little consideration in the many discussions that have taken

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place on this subject. Pipe or fittings made of cast steel last quite as well as ordinary gray cast iron in service, but conversely the pipe which may have been rolled out from a cast steel ingot lasts not one-tenth as long as the cast product. Now why should this be so?

Perhaps further light on this very involved question can be found in a recent investigation by a prominent tin plate manufacturer, who tried to ascertain the reason why the old iron links of the suspension bridge at Newburyport, Mass., have so successfully withstood the elements of wind and rain for more than one hundred years, little attention having been given to painting or protecting the metal. In reference to this the following statement is made in *The Corrosion of Iron*, a book published in 1916 by L. C. Wilson:

> To explain how or why these (links) have so successfully withstood the attacks of air and moisture for so many years is not as easy as it might seem for apparently some of our commonly accepted notions and theories as to what a good iron should and should not be do not hold, or at least are offset by other conditions. For instance, some of the links of the Newburyport bridge have been examined and found to be of very ordinary purity and of a most heterogeneous structure, segregation of the impurities being decidedly noticeable. The question of any inherent superiority in the iron itself was settled by heating and rolling one of the links into a sheet and exposing it to the weather, when it was found that it corroded quite as readily and extensively as the rolling mill product of today.

Structure of cast iron and rolled iron. At the top of the chart, Figure 1, which is a drawing reproduced from a standard text book on metallography, there are indicated the various commercial grades of iron products which are familiar to all. Beginning with the pig iron on the extreme right it will be noted that the carbon content is greater than 4 per cent. Next comes gray iron with a carbon content of 3.2 to 4.6 per cent. White iron is next with a carbon content of 2.2 per cent to 3.2 per cent. The iron which has a carbon content less than 2 per cent is known as steel, and this material may be rolled or manipulated while all other classes of iron must be cast into the desired shapes or objects. Glancing at the extreme left hand side of the chart, the various temperatures at which iron melts and freezes or solidifies may be observed. These temperatures are somewhat lower for gray iron than for steel, and are yet higher for pig iron than for gray iron. However, these very high temperatures, above 2200°F., apply only to the cast irons and cast steels, for when

we begin to investigate the temperatures at which steel pipe and wrought iron pipe are made we must confine our attention to that part of the chart below 1600°F. and between the limits 0 and 0.1 per cent carbon. This metal is worked at more than 1000°F. below its freezing temperature and hence does not attain its full crystal growth which can be restored to the internal structure of the pipe only by remelting.

As a result the pipe so made displays a form of flaking or exfoliation of its particles under the corrosive influence of ordinary service conditions. A very good analogy to iron rusting can be found in the geological structure of various grades of stone found on the

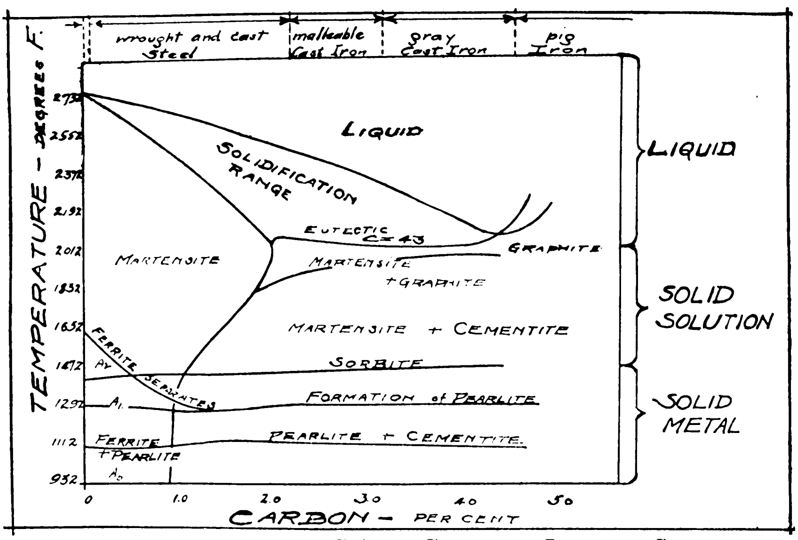

FIG. 1. TEMPERATURE-CARBON CURVES OF IRON AND STEEL

earth's surface. Those stones, such as granite, which were molded or "cast" ages ago at a very high temperature are far more durable than such materials as sandstone which were laid down and cemented together after the earth's surface had cooled to a low temperature. Both kinds of stone may be equally pure in silica and, moreover, we may make from sandstone as sturdy and durable a product as granite, if we but supply a sufficient amount of heat to fuse together the aggregate mass of silica crystals. Figure 2 is a photomicrograph of cast iron showing the bonding of the crystals.

Contrary to what has so often been stated with regard to cast iron

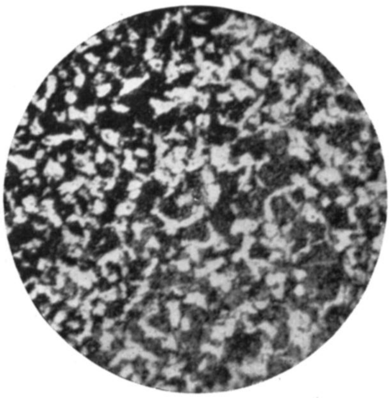

FIG. 2. PHOTOMICROGRAPH OF CAST IRON

FIG. 3. PHOTOMICROGRAPH OF STEEL (0.08% CARBON)

FIG. 4. RUST FORMATION ON CAST IRON

FIG. 5. RUST FORMATION ON WROUGHT IRON

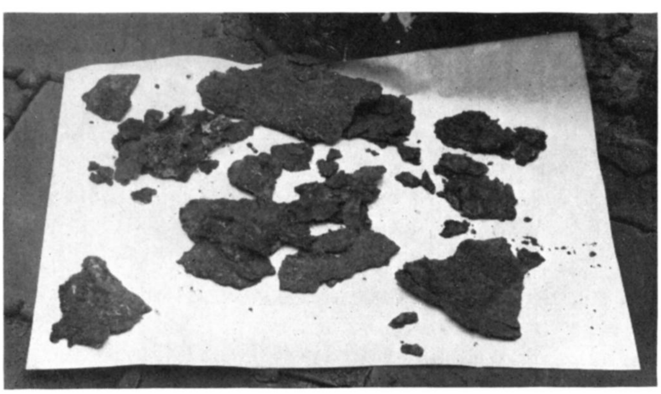

FIG. 6. RUST FLAKES FROM WROUGHT IRON AND STEEL PIPE

owing its life altogether to a "skin" resulting from the casting process, the author must diametrically disagree for the simple reason that castings have been in service for more than two hundred and fifty years and have shown no greater loss wherever the original casting skin has been totally absent.

The effect of rolling and of re-rolling is even more noticeable under the microscope than is the effect upon the internal structure of rolled steel. A bar of metal which is rolled or drawn "cold" will, if the process be carried to the extreme, present a structure viewed parallel to the direction of drawing, like the photo-micrograph shown in Figure 3. However, the pipe made from wrought iron is made at a final heat treatment of approximately 1200°F. which gives a fair degree of fusion to the gross slag particles distributed through the skelp from which the pipe is made. The inhibiting properties of this slag when carefully distributed through the wall section of the pipe compensates for the low temperature at which wrought iron pipe is rolled. Nevertheless both wrought iron and steel pipe last approximately the same under like conditions of service.

The author believes that the extraordinary qualities of cast iron pipe and of cast iron fittings can best be explained on the basis of heat treatment. At least it is the only explanation that seems to coincide with all of the observed corrosion phenomena which are incidents in the rusting of pipe in service.

Theories of corrosion. The many experimenters who have investigated this subject have evolved at least three different theories of iron pipe corrosion.

The hydrogen-peroxide theory explains the phenomena of rusting by assuming that when iron, water, and oxygen are in contact a chemical reaction takes place in which ferrous oxide, FeO, and hydrogen peroxide, H_2O_2, are formed. Then the ferrous oxide is supposed to react with a portion of the hydrogen peroxide to form a basic or hydrated oxide; rust, an insoluble basic oxide, is the final product.

A second theory, known as the carbonic acid theory, holds that rusting is always started by an acid. It assumes that even a very weak carbonic acid will first convert a portion of the iron into a ferrous salt, with the escape of hydrogen. Under the influence of oxygen and water the ferrous salt is oxidized to ferric hydroxide $2Fe(OH)_3$. The ferric hydroxide is insoluble and upon precipitation the original carbonic acid is liberated. The carbonic acid is then free to attack more iron and to repeat the process of reducing the iron to rust.

The third and perhaps most important theory of iron corrosion is known as the electrolytic theory. It rests on the assumption that when water comes into contact with an iron surface a certain amount of the iron goes into solution. This small amount of iron carried in solution in the water produces an electrolyte. The process of rusting is then explained by the familiar galvanic electrolysis which takes place between the points of high and low potential on the surface of the metal. The modern conception of the reactions which take place holds that they are accompanied by certain readjustments of the electrical state of the reacting ions and the iron must go into solution as a ferrous ion before it becomes oxidized.

If it were possible to summarize all of the painstaking research that has been carried on by investigators since 1800, we would probably find that one common point has always been mutually agreed upon. It has always been admitted that the iron particles must be in direct contact with oxygen and moisture before rusting can take place. In all likelihood, it is probably close to the truth to say that under varying conditions of service for iron pipe, any one or all of the corrosion theories actually apply during the process of rusting. As for inhibiting or preventing the rusting of an iron pipe line, the problems, both theoretical and practical, seem to sum up in the one proposition of keeping moisture and oxygen from reaching the iron itself. Expressed in different terms it is the old question of getting a protective coating on all exposed parts of the pipe.

Protective skin on cast iron. There is an entirely different kind of surface rust formation on cast iron pipe than is to be found on the surface of a pipe made of rolled iron or steel. Figure 4 shows the rust formation on cast iron and Figure 5 that on wrought iron pipe after they have been in the same service for 18 years. On the surface of a cast iron pipe, whether machined or fractured or not, may be observed a reddish-brown colored iron oxide which is very hard, and so tenaciously covers the surface of the pipe that it penetrates down between every surface crystal and forms a perfectly impervious coating which is not penetrated by the moisture and oxygen. Hence galvanic action stops on such a surface and the life of the pipe is insured by the very virtue of the oxide itself contained on the surface.

On the other hand let us observe the surface of a piece of wrought iron pipe or a piece of steel pipe. In Figure 6 we see a loose scaling formation of rust which is soft and pervious to moisture and oxygen. These flakes of rust are very readily removed with a pen-knife or

the thumb nail from the surface of the pipe. Once the rust scale drops away the fresh bright particles of the iron are exposed to the oxygen and moisture so that further rusting takes place on each fresh surface until the entire wall thickness of the pipe has been destroyed. The surface scales on wrought iron materials accelerate galvanic action, whereas the rust formation on cast iron has just the reverse quality, namely, the prevention of galvanic electrolysis. The cause for the gradual slowing up of rust action on cast iron seems, therefore, to be thoroughly explained by the quality of the surface oxide.

Plumbing and wasted water. The part which bad plumbing plays in the enormous waste of public water is a very significant reason why water works officials should pay more attention to the details of the piping installed in the buildings. The habit has been too common of thinking that the responsibility ends at the corporation cock on the street main or at the meter. That responsibility should not end short of the spigot on each plumbing fixture.

The New England Water Works Association received last year an excellent report on service pipes in which the following table was given to show the comparative life of some materials which have been used:

	YEARS BEFORE TROUBLE BEGINS	LIFE OF PIPE YEARS
Plain iron or steel pipe	12	16
Galvanized pipe	15	20
Lead pipe	10	35
Lead lined pipe	10	23
Cement lined pipe	14	28

These data are valuable as giving some idea of the amount of water wasted from steel and wrought iron service pipes, which wastes through rust holes in the pipe long before the trouble is detected. Moreover, it becomes difficult to learn the amount of wastage until the line is torn up and replaced. The table also shows that galvanized pipe is little better than black pipe.

Cast iron pipe for service lines in the streets as well as for the mains has been installed at low cost, and perfect results can be obtained provided satisfactory joints are used. The minimum size should be 2 inch internal diameter and this can be laid at approximately the same cost per foot as 1 inch lead service pipes. Nothing

will ever reduce the economic loss from wasted water, amounting to $4,000,000 in the United States annually, so much as the general adoption of cast iron pipe with joints capable of remaining permanently tight. Such piping should begin at the pumping station and continue as far as the plumbing fixtures in the buildings. For pipes less than 2 inches internal diameter the material should consist of brass or copper. The general rule should be to use 2-inch cast iron service pipes, but it is not necessary to provide more than a $\frac{3}{4}$- or 1-inch tapping on the main. The meter may also be of 1-inch size on a 2-inch service pipe without causing any appreciable pressure loss due to friction.

In connecting the service pipe to the street main the present practice of using a short lead gooseneck between the cast iron pipe and the brass corporation cock should be followed in order to provide for settlement and expansion. The service piping must have joints which are flexible as well as tight against pressure. Such a joint is on the market.

The bell and spigot ends of the pipe are machined at slightly different tapers and bolts are used for assembling the joint. When the joints have been made tight against pressures the bolts are usually loosened off and this construction remains permanently tight as there is no chance of deterioration either at the joint or at any part of the pipe system. The Underwriters' Laboratories have tested and approved for high-pressure fire service the cast iron piping having this joint.